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THE SAN FRANCISCO BAY AREA--



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UNIVERSITY OF CALIFORNIA

ON SHAKY GROUND

FEBRUARY 1987

ASSOCIATION OF BAY AREA GOVERNMENTS

CREDITS

Author

Jeanne B. Perkins -- ABAG Earthquake Program Manager

Maps

ABAG's geographic information system (BASIS) is operated by Geogroup Corporation
(Paul M. Wilson, President)

Assistance

Cartography -- Eureka Cartography
Graphics -- Peter Beeler
Word Processing -- Peggy Green

ABAG Management

Revan A. F. Tranter -- Executive Director
Eugene Y. Leong -- Deputy Executive Director

Earthquake Mapping Applications Committee

Ed Danehy -- Engineering Geologist, Alameda County Public Works Agency
Bob Gaiser -- Planner, Sonoma County Planning Department
Fred Herman -- Chief Building Official, City of Palo Alto
John Hutchins, Nancy Walker -- City of Hayward Fire Department
Mark Isaacson -- Associate Planner, Daly City Department of Community Development
Tom Jenkin -- Emergency Facility Planner & Architect, San Francisco Office of
Emergency Services
Frank Lew -- Superintendent, Bureau of Building Inspection, San Francisco
Todd Nelson -- Planning Geologist, Contra Costa County Planning Department
Doug Wirtz -- Fire Inspector, City of Fairfield Public Safety Department

Cover: The map is a reproduction of the regional map of risk of ground shaking damage for tilt-up concrete buildings.

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TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	ii
Figure -- Bay Area Faults	iv
THE BAY AREA IS EARTHQUAKE COUNTRY	1
Figure -- How Big is Big? -- Measuring Earthquakes	2
GROUND SHAKING -- THE FORGOTTEN HAZARD	3
Figure -- Geologic Materials and their Ability to Amplify Ground Shaking	4
Figure -- Ground Shaking Intensities from an Earthquake on the San Andreas Fault	6
Figure -- Ground Shaking Intensities from an Earthquake on the Hayward Fault	7
Figure -- Maximum Ground Shaking Intensity	9
Figure -- Risk of Ground Shaking Damage* for Tilt-Up Concrete Buildings	12
Figure -- Risk of Ground Shaking Damage* for Concrete and Steel Frame Buildings	14
Figure -- Risk of Ground Shaking Damage* for Wood Frame Dwellings	16
[*Cumulative Damage Potential]	
LOCAL GOVERNMENT MITIGATION STRATEGIES	18
1. Land Use Controls	19
2. Geotechnical Studies and Environmental Assessments	20
3. Building Codes	21
4. Non-Structural Mitigation	22
5. Existing Hazardous Buildings	23
6. Hazardous Materials	24
7. Infrastructure or Lifelines	25
8. Disclosure Requirements	26
9. Disaster Response Planning	27
10. Reconstruction/Redevelopment	28
11. Public Education	29
12. Political Support Strategies	30
ABOUT THE MAPS	31
REFERENCES	32

SUMMARY

The San Francisco Bay Area is in "earthquake country".

In most earthquakes, ground shaking is the greatest hazard, causing the largest percentage of damage.

Albert M. Rodgers
U.S. Geological Survey

In some earthquakes, the surface of the ground can rupture along a fault -- or a landslide can be triggered -- or underground sand layers may flow (liquefy) -- or a tsunami (tidal wave) may be generated in water. But in all earthquakes, the ground shakes. In larger magnitude earthquakes, more ground shakes, and it shakes more severely. Ground shaking has and will cause damage tens of miles away from the fault source.

Three major factors affect the severity of ground shaking at a site (that is, its intensity) in an earthquake:

- the size (magnitude) of the earthquake;
- the distance from the site to the fault that generated that earthquake; and
- the geologic materials at the site.

The first map that follows shows the major faults in the Bay region. There are at least thirty faults in this area that can generate earthquakes. The second map shows the geologic materials in the central Bay Area. These materials are grouped into categories of similar susceptibility to shaking from earthquakes. The soils near the Bay (called Bay mud by geologists) are the most susceptible to shaking.

Using this information on fault location and geology, together with assumptions about typical earthquakes, it is possible to generate maps showing the expected severity of ground shaking from hypothetical earthquakes. Maps of two such scenarios, one for the San Andreas fault and a second for the Hayward fault, are included.

ABAG, with funding from the U.S. Geological Survey, has generated such scenario maps for thirty earthquakes. Because using these maps can become unwieldy, they have been combined them into two types of composite maps. The first was generated by looking down through the stack of thirty maps and selecting, for each site, the "worst case" or highest intensity occurring on any of the maps. The resulting map is the maximum ground shaking intensity map. The second type of composite map was generated by weighting the importance of each of the scenario intensity maps based on the recurrence interval of the earthquake and associated damage (for a range of three building types). These three maps are generated by adding the expected damage from all the earthquakes to form "risk" maps.

When the ground shakes, damage occurs to buildings, facilities and their contents. People are injured and killed. Businesses can't function and the economy suffers. A dozen options for avoiding, reducing or otherwise mitigating these results include:

- land use and zoning controls;
- requirements for soils and geotechnical studies;
- special building design requirements;
- special requirements for non-structural components;
- hazardous building retrofitting and abatement;
- special requirements related to hazardous materials;
- infrastructure and lifeline requirements;
- disclosure requirements and posting of signs;
- disaster response planning;
- reconstruction and redevelopment planning;
- public information and education programs; and
- strategies for maximizing political support.

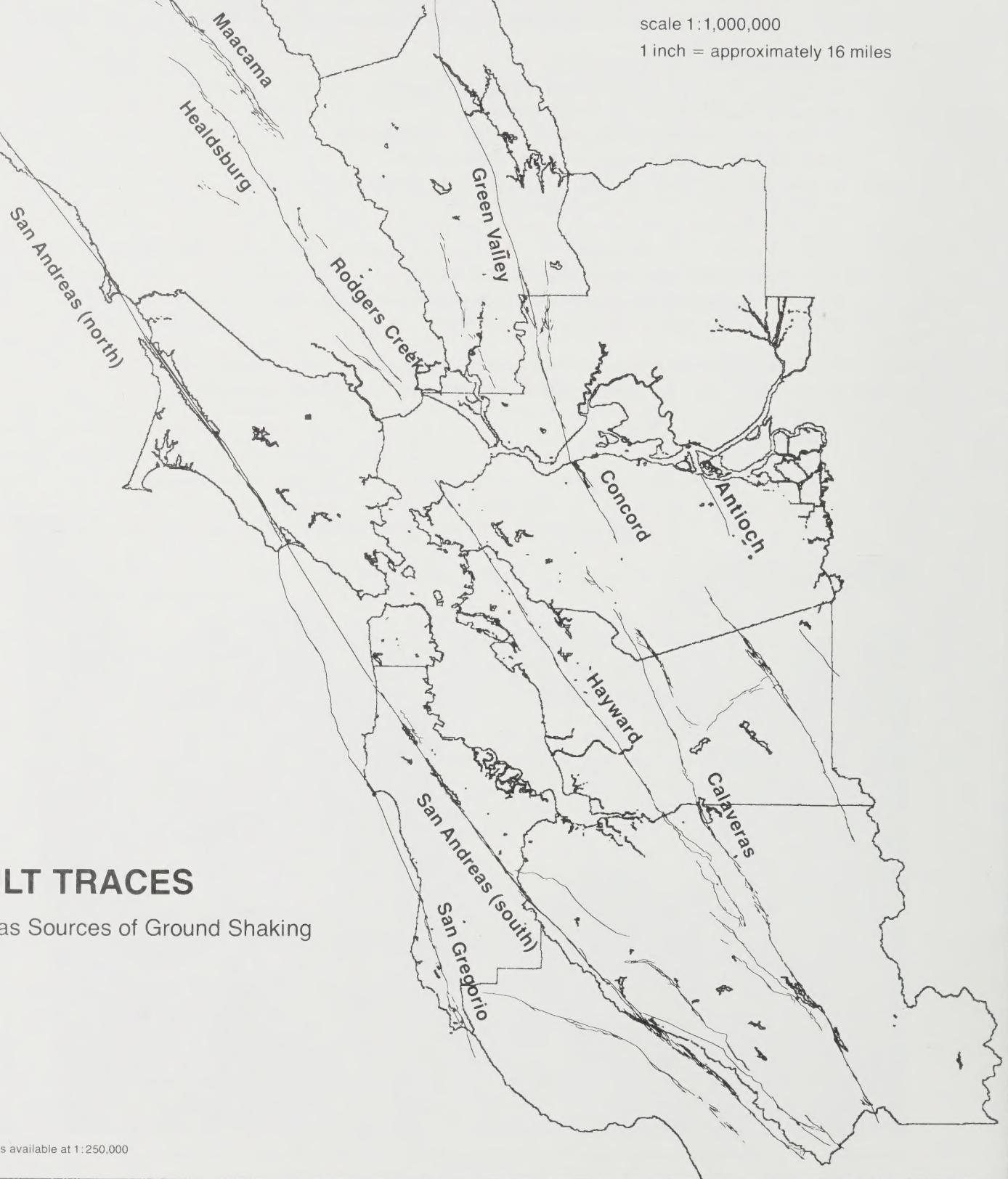
All of these strategies are important and useful in improving safety plans of local governments. We must do a better job of preparing for the ride of our lives.



photo courtesy of H. J. Degenkolb Associates

scale 1:1,000,000

1 inch = approximately 16 miles



FAULT TRACES

Used as Sources of Ground Shaking

Ozalid copies available at 1:250,000

BASIS

Bay Area Spatial Information System

 ABAG

ASSOCIATION OF BAY AREA GOVERNMENTS

THE BAY AREA IS EARTHQUAKE COUNTRY

The fact that a devastating earthquake occurred in 1906 -- the San Francisco earthquake -- is common knowledge. But many earthquakes that can cause damage (over magnitude 5.0) have affected the Bay area; over 40 such events have occurred in the last 150 years -- for an average of one every 3 to 4 years. Larger earthquakes generally affect larger areas; *San Francisco's* earthquake caused extensive damage in Oakland, San Jose and Santa Rosa. Larger earthquakes also can cause more severe damage.

A major earthquake will strike the San Francisco Bay Area. The only question is when...

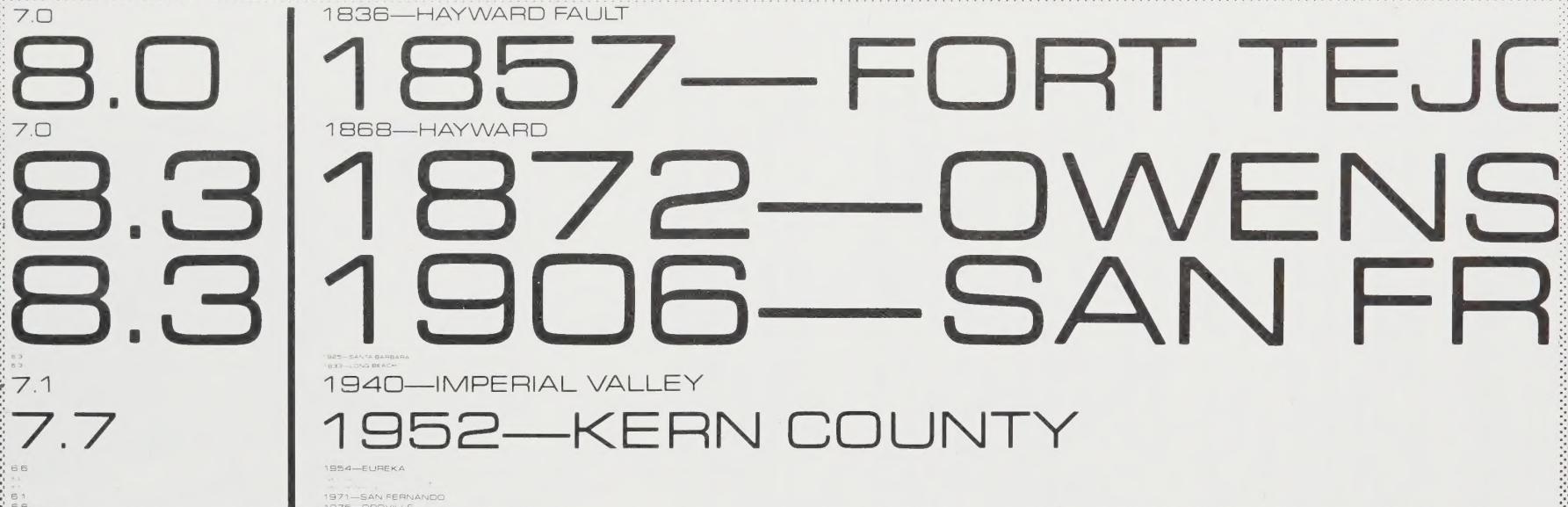
Karl Steinbrugge -- Former Chair
California Seismic Safety Commission

Earthquakes occur in the Bay area when forces deep underground cause the rocks beneath us to break and snap past each other. If the break extends to the surface, we see movement on faults ("surface rupture"). But earthquakes can occur when the fault break does not extend to the surface. The snapping of the ground generates vibrations or waves in the rock which we feel as ground shaking. Because faults are weaknesses in the ground, earthquakes tend to occur over and over on these same faults. The ground shaking can cause direct damage to buildings, roads, and utilities, as well as trigger the flowing of sand layers (liquefaction), landslides, and tsunamis (tidal waves), thereby indirectly affecting these same facilities.

Most damage associated with past -- and future -- earthquakes is related to the shaking of the ground itself. Yet, at the same time, many existing local and State government programs and regulations focus on other earthquake hazards, such as surface fault ruptures. Our purposes in preparing this booklet are to expose ground shaking as a significant hazard, to show (using maps) the areas with the most expected problems, and to suggest ways to mitigate these problems.



How Big is Big?—Measuring Earthquakes



Magnitude

The magnitude of an earthquake is a measure of the amount of energy released by the quake. Magnitude is measured on a scale devised by Dr Charles Richter. On this logarithmic scale each whole number represents a magnitude of energy release roughly 31 times the next lower number. Thus an earthquake measuring 7 on the destructive scale releases 31 times more destructive energy than a magnitude 6 earthquake.

The major destructive quakes in California during the last 150 years are listed above. **THE SIZE OF THE TEXT WHICH IDENTIFIES EACH EARTHQUAKE REFLECTS THE MAGNITUDE OF THE QUAKE.** Clearly California has not seen a truly major earthquake in the last 1/2 of those 150 years!

Intensity

Intensity is a measure of the effect rather than the energy release of an earthquake. The measurement is necessarily subjective as it is based on personal observations and thus reflects local conditions. Two intensity scales are commonly used—the San Francisco scale and the Modified Mercalli scale. Their relationship is illustrated below.

Intensity scales are useful in mapping the effects of previous earthquakes or in earthquake-prone areas, the likely effects of future quakes.

San Francisco Scale

- Very violent—A
- Violent—B
- Very Strong—C
- Strong—D
- Weak—E

Modified Mercalli Scale

- XII—Massive Destruction
- XI—Utilities Destroyed
- X—Most Small Structures Destroyed
- IX—Heavy Damage
- VIII—Moderate to Heavy Damage
- VII—General Non-structural Damage
- VI—Felt By All People

GROUND SHAKING -- THE FORGOTTEN HAZARD

Maps predicting the severity of earthquake ground shaking usually depict intensity. Three factors affect the *intensity* experienced at a location:

- the size of the earthquake, or *magnitude*;
- the distance to the earthquake fault; and
- the geologic materials underlying the site.

Larger magnitude earthquakes generally cause the ground to shake harder and longer, and they affect larger areas. This relationship is generally well understood.

On the other hand, many commonly believe that most damage will occur at the epicenter of the earthquake. (The epicenter is the point on the surface above the location where the fault begins to slip.) However, the earthquake epicenter is **NOT** the point at which most damage occurs. The fault slippage can be tens of miles long and waves are generated along the entire length of the fault that ruptures. Thus, predictions of ground shaking intensity are based not on distances from hypothetical epicenters, but on distances from known faults.

This is the myth of the epicenter. The word has become a functional synonym for ground zero.

Bruce MacGregor
San Francisco Magazine, June 1982

The final factor affecting intensity at a site is the geologic material underneath that site. Thick, loose soils tend to amplify and prolong the shaking. The worst such soils in the Bay Area are the loose clays bordering the Bay -- the Bay mud. The rock that is least susceptible to shaking is granite. The remaining materials fall between these two extremes, with the thicker soils in the valleys being more susceptible to shaking and the rocks in the hills being less susceptible. The map that follows groups the geologic materials in the region into eight categories that will respond similarly in earthquakes.

GEOLOGIC UNITS

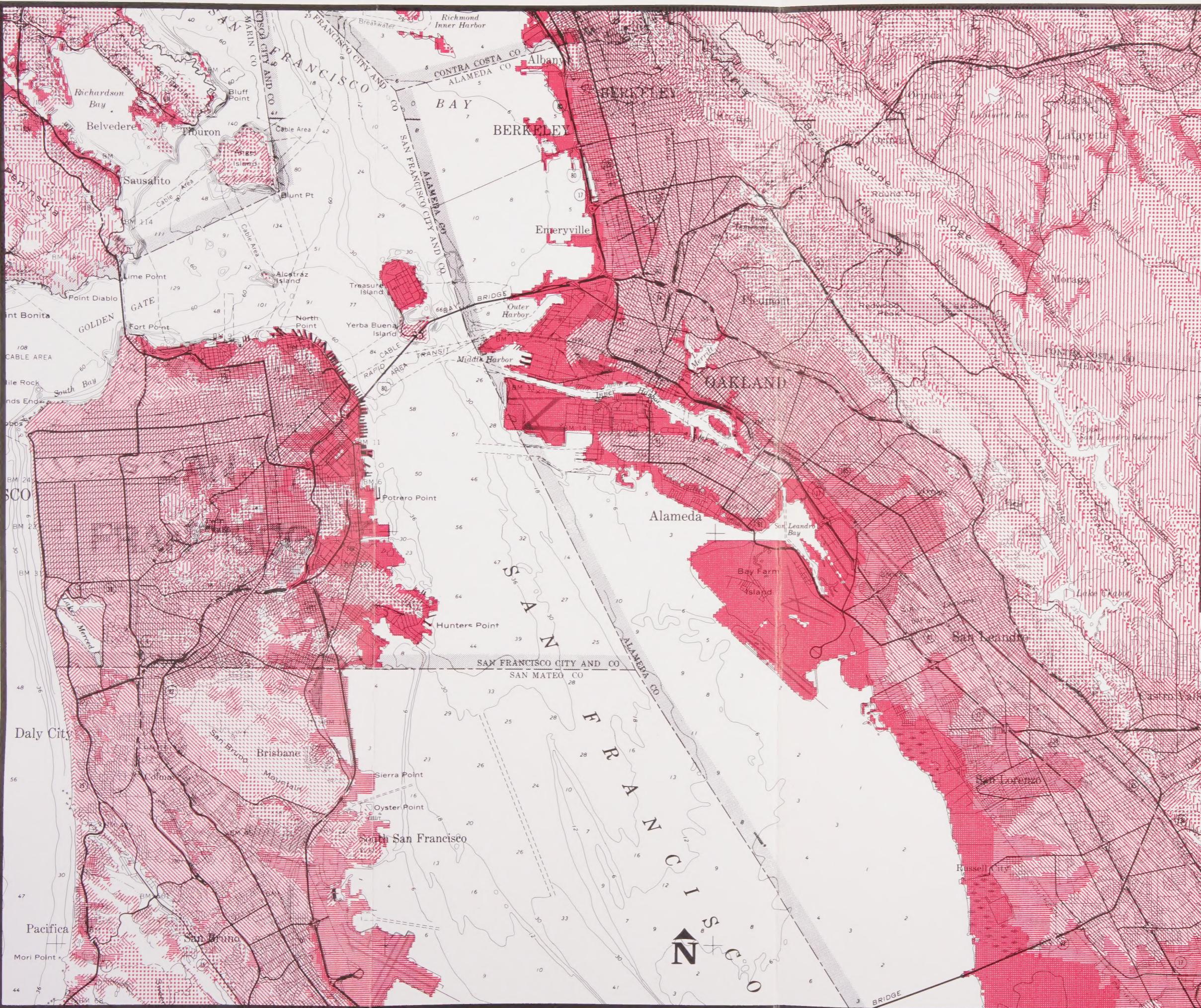
CENTRAL SAN FRANCISCO BAY REGION

Grouped into Categories of Similar Susceptibility to Ground Shaking

- Extremely High Susceptibility
- Very High
- High
- Moderately High
- Moderate
- Moderately Low
- Low
- Very Low

scale 1:125,000 (1 inch = approximately 2 miles)

Developed by the Association of Bay Area Governments
February 1987



Producing Scenario Intensity Maps

ABAG staff, funded over the last ten years by the U.S. Geological Survey, has produced several ground shaking intensity maps. Because of the complex relationship among magnitude, fault distance and geology, the maps were generated using its computer-based geographic information system (Bay Area Spacial Information System -- BASIS).

The most basic intensity map files were produced for hypothetical large earthquakes on each of the 31 active faults in the region shown on page 2 and listed below.

Ten of those intensity map files have been used to generate maps available from ABAG. Portions of two of those maps follow -- one for a magnitude 8.4 earthquake on the San Andreas fault, and the second for a magnitude 6.9 earthquake on the Hayward fault -- are shown on the following two pages. Note on these maps the variety of intensities produced from a single earthquake event.

TABLE -- ACTIVE FAULTS IN THE SAN FRANCISCO BAY AREA

Fault	Magnitude of Earthquake Used For Maps	Recurrence Interval For That Magnitude ⁴ Earthquake ⁴ (in years)	Fault	Magnitude of Earthquake Used For Maps	Recurrence Interval For That Magnitude ⁴ Earthquake ⁴ (in years)
San Andreas ¹	8.4	1,000	Cordelia	5.9	—
Hollister-Bolinas	7.2	100	Sargent (N of ~37° lat)	6.4	—
Bolinas-Cape Mendocino	7.5	100	Sargent (S of ~37° lat)	5.9	70
Calaveras ¹	7.3	300	Las Positas	6.3	—
Calaveras-Paicines	6.9	100	Greenville	6.9	—
Calaveras-Sunol	6.7	100	Faults near Trenton	6.2	—
Pleasanton	5.5	—	Tolay	5.7	—
Concord/Green Valley	7.0	200	Faults east of Bennett Valley and Santa Rosa	6.8	—
Antioch	6.4	—	Zayante	6.8	—
Hayward (incl. Crosley)	6.9	200	Berrocal	7.4	—
Healdsburg/Rodgers Creek	6.8	200	Midway	6.8	—
Maacama ³	7.1	300	San Joaquin	7.3	—
San Gregorio	7.1	200	Monte Vista	7.1	20,000
Verona	6.8	—	Coyote Creek	6.8	—
Silver Creek	7.1	—	Piercy	6.4	—
Evergreen	6.9	—	Serra	6.8	—
Dunnigan Hills	6.8	—	Ortigalita	6.2	40,000
West Napa	6.2	—			

¹ The entire San Andreas and Calaveras faults are used in the maximum intensity mapping. The shorter segments are used for the risk mapping because greater annualized damage would occur.

² Note that it is not considered likely that the entire San Andreas would rupture in a single event.

³ Including the NE of Alexander Valley and Alexander Valley faults.

⁴ For a point on the fault. For some faults, insufficient evidence is available to establish recurrence intervals.

GROUND SHAKING INTENSITY FROM AN EARTHQUAKE ON THE SAN ANDREAS FAULT

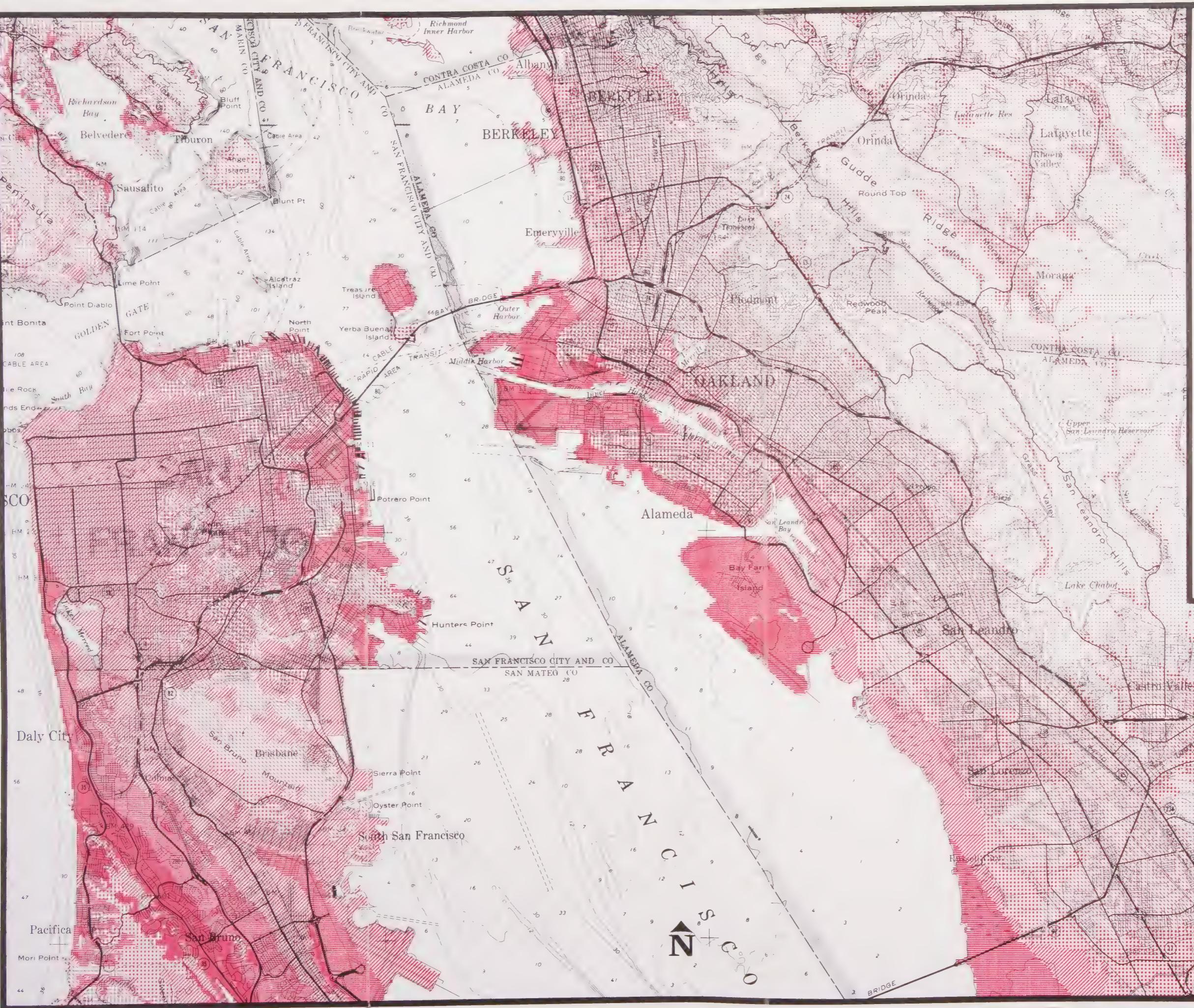
CENTRAL SAN FRANCISCO BAY REGION

San Francisco Intensity

- A--Very Violent
- B--Violent
- C--Very Strong
- D--Strong
- E--Weak
- <E--Negligible

scale 1:125,000 (1 inch = approximately 2 miles)

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February 1987



GROUND SHAKING INTENSITY FROM AN EARTHQUAKE ON THE HAYWARD FAULT

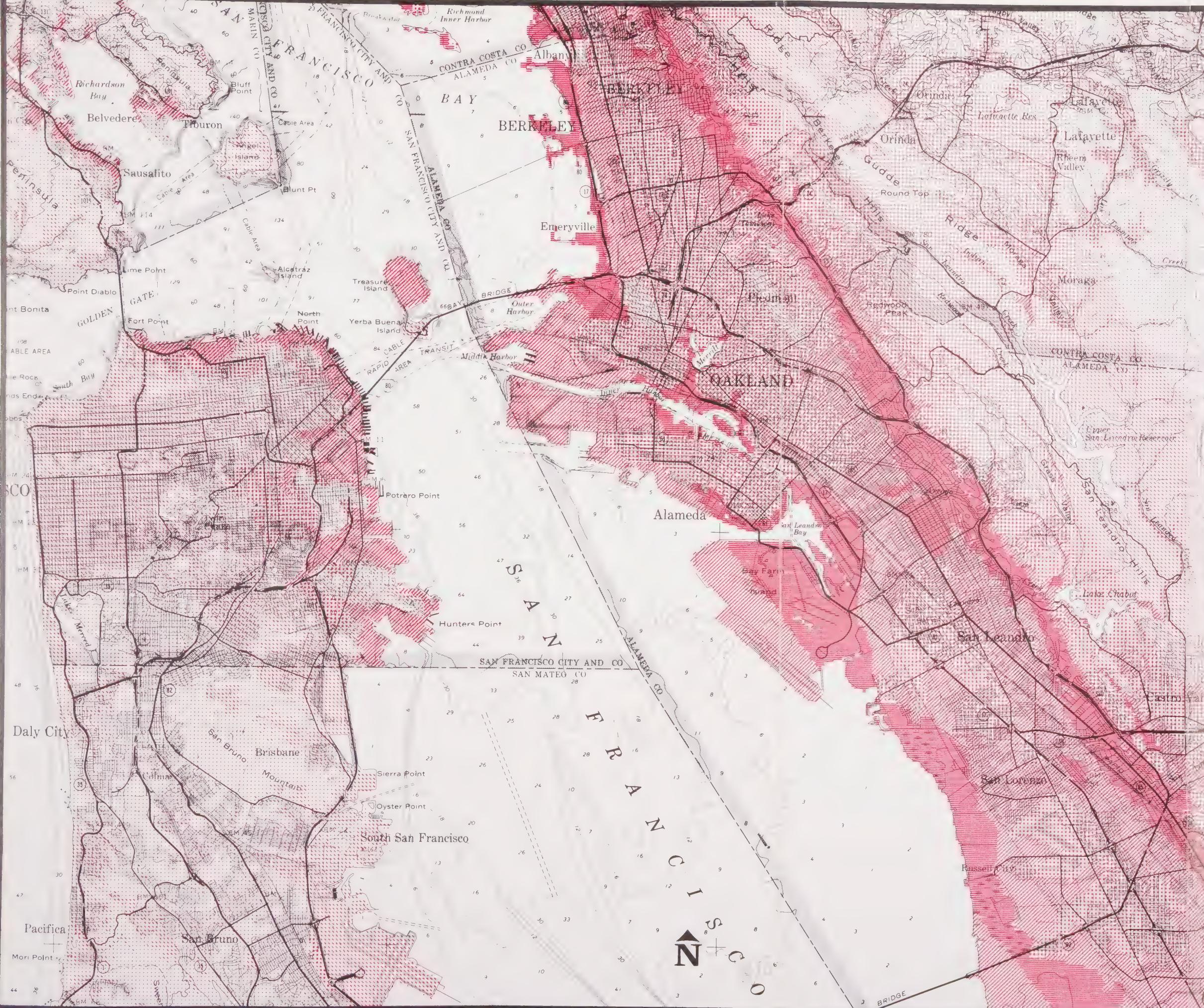
CENTRAL SAN FRANCISCO BAY REGION

San Francisco Intensity

- A--Very Violent
- B--Violent
- C--Very Strong
- D--Strong
- E--Weak
- <E--Negligible

scale 1:125,000 (1 inch = approximately 2 miles)

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Mapping Maximum Intensity

Dealing with such a series of intensity maps can be unwieldy, as well as confusing to use. Therefore, we have combined the maps in two separate ways. The first type of map is a maximum intensity map. It was generated by using the highest intensity for every area from each of the individual fault-intensity maps. This process is one in which the computer, in effect, looks down through the stack of intensity maps and picks the highest intensity that occurs on any of the maps to create a composite map.

The maximum intensity maps can be used with information about existing buildings to forecast locations of maximum damage. This information is crucial to planning for emergency response or for designating areas of critical concern.

This maximum intensity map is based on data related to faults and geology. It does not include any information on existing land use or building type and age. Therefore, it cannot be used alone in making estimates of current property at risk. General data on the Bay Area's building stock is contained in a separate report, Building Stock and Earthquake Losses -- the San Francisco Bay Area Example (May 1986).



photo courtesy of H.J. Degenkolb Associates

MAXIMUM GROUND SHAKING INTENSITY

CENTRAL SAN FRANCISCO BAY REGION

San Francisco Intensity

- A--Very Violent
- B--Violent
- C--Very Strong
- D--Strong
- E--Weak
- <E--Negligible

scale 1:125,000 (1 inch = approximately 2 miles)

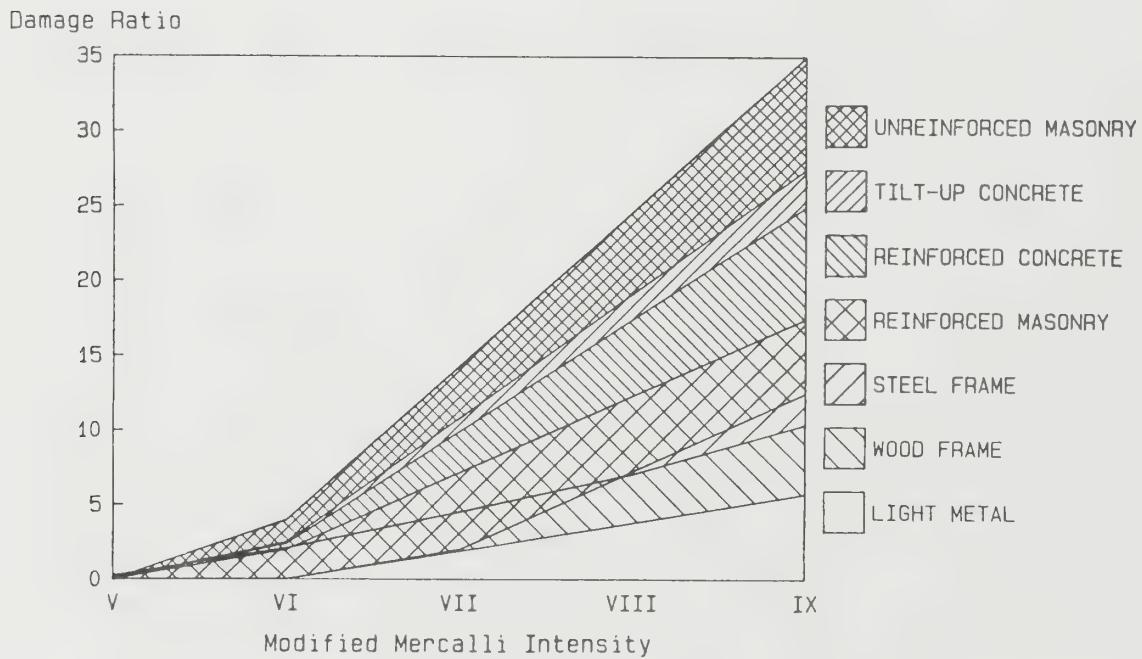
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Mapping Risk

A second technique for combining the individual fault-intensity maps involves using data on how often earthquakes are expected to occur on each fault to weight the importance of these maps. The information on each of the fault-intensity maps is then added together to create a composite risk map. One must, however, come up with a way to convert intensity (a subjective scale) to a numeric scale before the individual intensity maps can be added together. This conversion can be made using data on expected damage for each intensity level. Expected damage can be estimated by generalizing experience from past earthquakes and applying it to future hypothetical events. The generalized information is available as a damage ratio or damage factor for each intensity level. This factor is defined as the cost of repairing a building divided by the cost of replacing that building. It can be viewed as a percentage loss and is expressed in percentages. Curves of these loss percentages, or damage ratios, are shown below for seven typical building types. The curves can provide a simple means of gauging the relative performance of buildings during earthquakes. These curves represent damage to buildings incorporating intermediate earthquake-resistant design. The curves for each building type will be higher if ordinary to poor performance is expected, and lower if superior performance is expected.

EXPECTED DAMAGE
TO SELECTED BUILDING TYPES



Since these curves depend on the building type, any risk map using the curves must be building-type specific. We chose to create three risk maps based on these curves--one for buildings with relatively poor performance expected, a second for those with intermediate performance, and a third for those buildings expected to behave relatively well. The first map uses a curve one-third of the way between tilt-up concrete and unreinforced masonry, representing risk for tilt-up structures in which ordinary to poor performance is expected. [Note that the damage curve for an unreinforced masonry building is not that

much steeper than this poorer tilt-up building. The risk map for such tilt-up construction is therefore not substantially different than one that might be prepared for unreinforced masonry structures.] The second map is based on the curve for reinforced masonry, although steel frame buildings with relatively poor expected performance for their type of construction, and concrete buildings with relatively superior expected performance for their type of construction, will have comparable curves. The third map is based on the wood frame curve shown.

The damages from a single event are then multiplied by a recurrence interval and *discounted* to their *present value*. "Discounting" is the act of reducing the value of some future dollar amount (in this case, a loss) to its present value by a given amount to cover interest -- the reverse of what happens in an interest-bearing savings account.

The resulting expected loss percentages (provided in the map explanations) can be compared to increases in construction costs that could reduce the damage using standard cost-benefit analysis.

Because of the additive process used to produce these "risk" maps, they can also be viewed as maps of "cumulative damage potential". This title has been used by both ABAG and the U.S. Geological Survey when publishing these same maps.

The explanation boxes on the three risk maps are identical. The shade patterns are the same on all three maps to best illustrate the variations in damage based both on geographic location and building type or construction quality.

These risk maps are more valuable for developing planning and mitigation programs than the maximum intensity maps because they build in data about the frequency of earthquakes on different faults. Another difference between the two types of maps becomes apparent if you look at two areas, one near a fault and one on the unconsolidated soils next to the Bay. On the maximum ground shaking intensity map, the two sites may appear equivalent. Yet on any of the risk maps, the site next to the Bay is shown as having a greater potential for damage; the fault site is only subject to violent shaking if that particular fault is the source of the earthquake, while the site next to the Bay is subject to very strong or violent shaking if any of a number of faults are the earthquake source.

These risk maps are based on data related to faults, geology, frequency of earthquakes, and statistical damage patterns. They do NOT include any information on EXISTING land use or EXISTING building stock. Therefore, they cannot be used alone in making estimates of current property at risk. General data on the Bay Area's building stock is contained in a separate report, Building Stock and Earthquake Losses -- the San Francisco Bay Area Example (May 1986).

RISK OF GROUND SHAKING DAMAGE FOR TILT-UP CONCRETE BUILDINGS

CENTRAL SAN FRANCISCO BAY REGION

Cumulative Damage Potential Expressed As Expected Damage Discounted to Present Value

Extremely High Cumulative Damage Potential (6.1+%)

Very High (5.1 - 6.0%)

High (4.1 - 5.0%)

Moderately High (3.1 - 4.0%)

Moderate (2.1 - 3.0%)

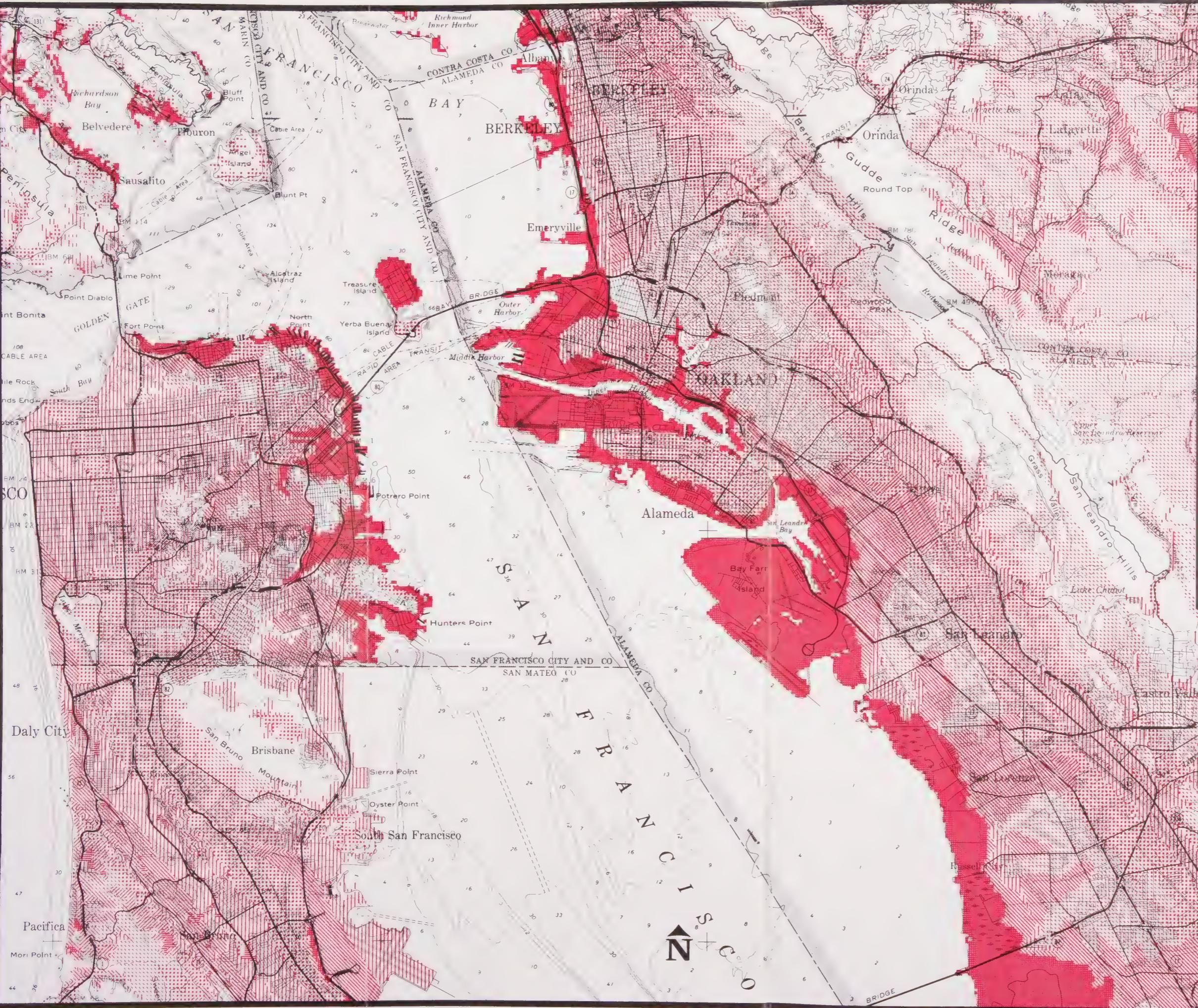
Moderately Low (1.1 - 2.0%)

Low (.3 - 1.0%)

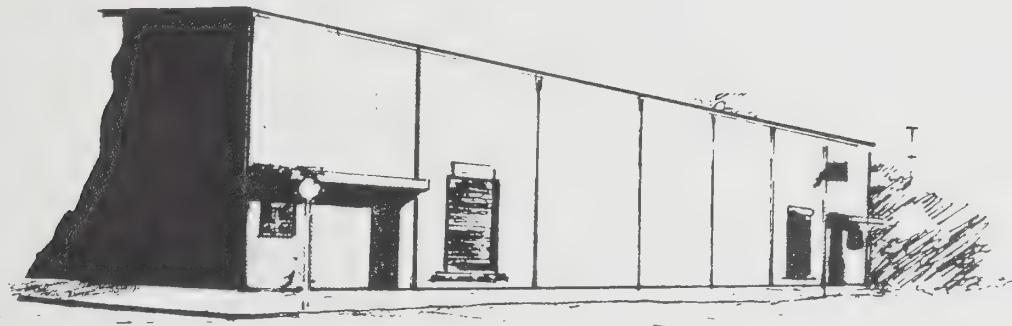
Very Low (0 - .2%)

scale 1:125,000 (1 inch = approximately 2 miles)

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February 1987



Typical Tilt-Up Concrete Construction



Sample Tilt-Up Concrete Damage



photo courtesy of H.J. Degenkolb Associates

RISK OF GROUND SHAKING DAMAGE FOR CONCRETE AND STEEL BUILDINGS

CENTRAL SAN FRANCISCO BAY REGION

Cumulative Damage Potential Expressed As
Expected Damage Discounted to Present Value

Extremely High Cumulative
Damage Potential (6.1+%)

Very High (5.1 - 6.0%)

High (4.1 - 5.0%)

Moderately High (3.1 - 4.0%)

Moderate (2.1 - 3.0%)

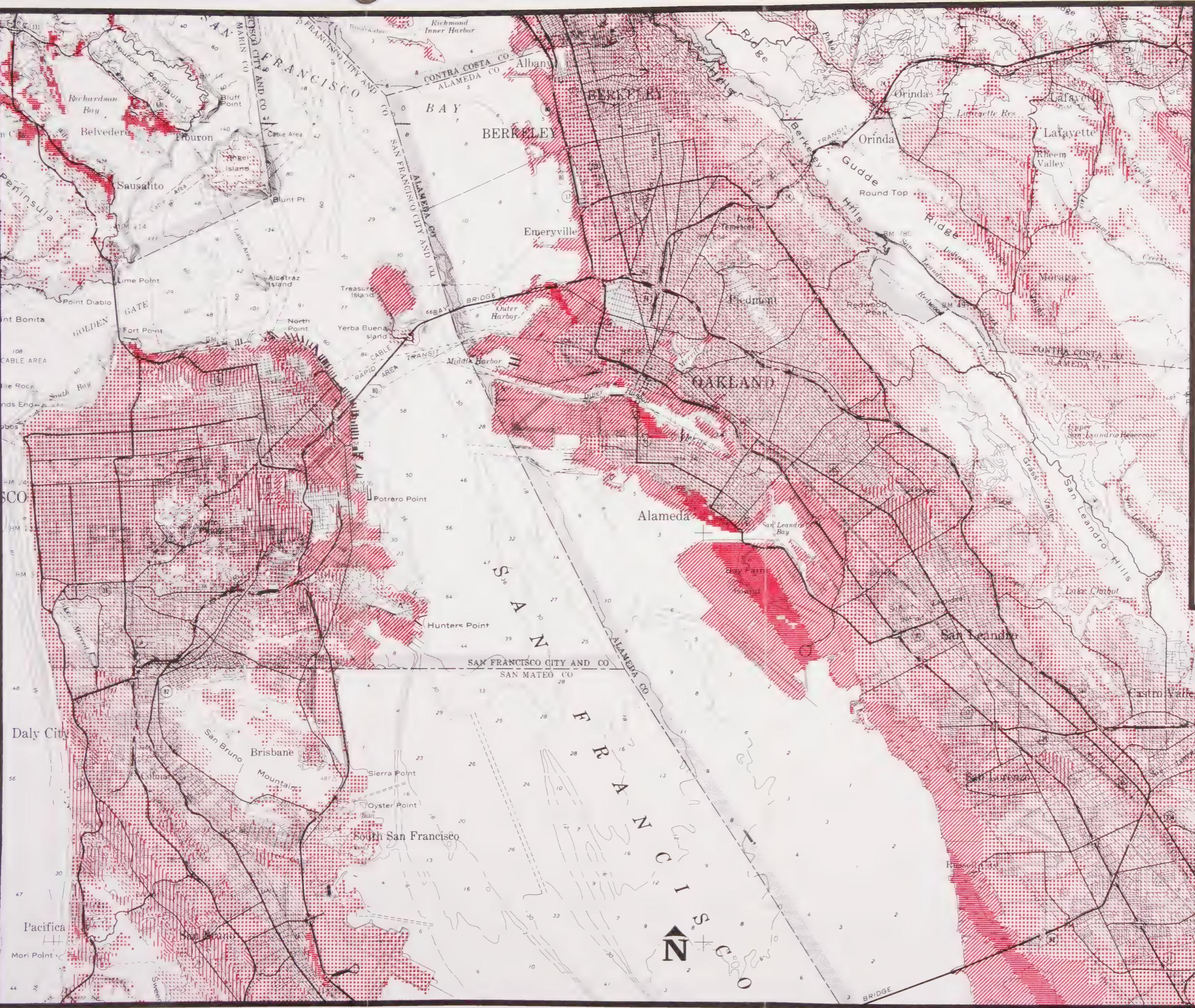
Moderately Low (1.1 - 2.0%)

Low (.3 - 1.0%)

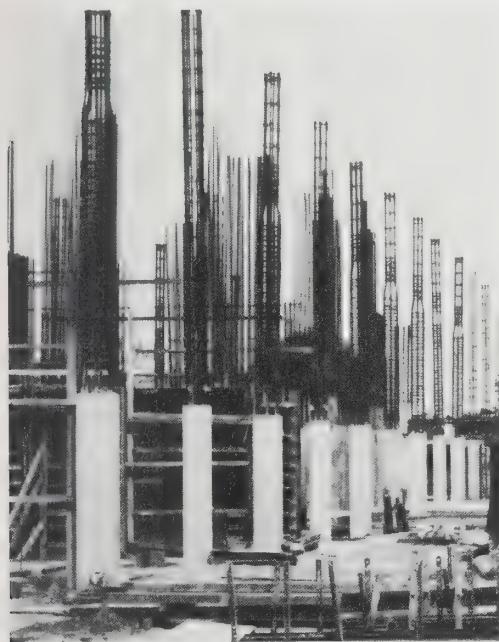
Very Low (0 - .2%)

scale 1:125,000 (1 inch = approximately 2 miles)

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**Typical Reinforced
Concrete Construction**



**Typical Steel Frame
Construction**



**Sample Reinforced
Concrete Damage**



RISK OF GROUND SHAKING DAMAGE FOR WOOD FRAME DWELLINGS

CENTRAL SAN FRANCISCO BAY REGION

Cumulative Damage Potential Expressed As Expected Damage Discounted to Present Value

Extremely High Cumulative Damage Potential (6.1+%)

Very High (5.1 - 6.0%)

High (4.1 - 5.0%)

Moderately High (3.1 - 4.0%)

Moderate (2.1 - 3.0%)

Moderately Low (1.1 - 2.0%)

Low (.3 - 1.0%)

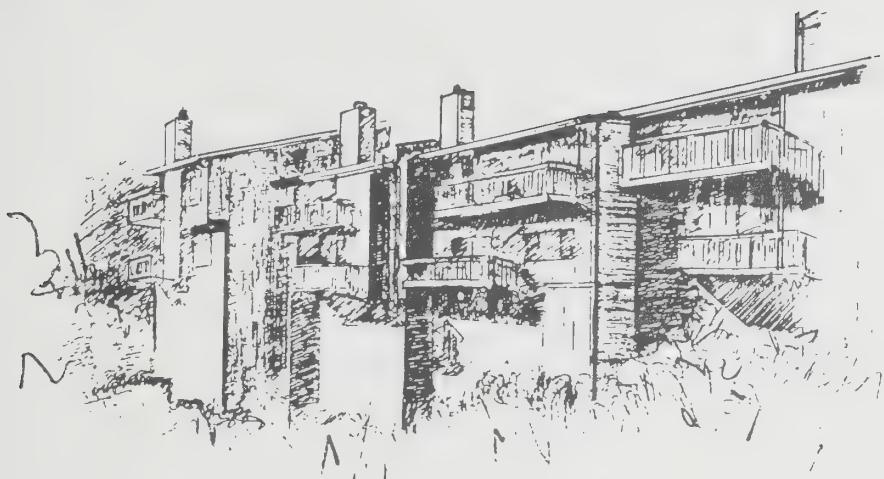
Very Low (0 - .2%)

scale 1:125,000 (1 inch = approximately 2 miles)

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Typical Wood Frame Construction



Sample Wood Frame Damage



photo courtesy of H.J. Degenkolb Associates

LOCAL GOVERNMENT MITIGATION STRATEGIES

All of the maps included in this booklet should make one fact obvious:

ALL BAY AREA LAND WAS NOT CREATED EQUAL

Large variations in the level of ground shaking hazard exist in the San Francisco Bay Area. It therefore makes sense that local government programs to deal with these problems should take into account these differences.

Where Nature is neglected, it may become a formidable opponent.

Robert Brown and William Kockelman
Geologic Principles for Prudent Land Use
(U.S. Geological Survey, 1983)

The following pages outline a dozen options for mitigation including:

- land use and zoning controls;
- requirements for soils and geotechnical studies;
- special building design requirements;
- special requirements for non-structural components;
- hazardous building retrofitting and abatement;
- special requirements related to hazardous materials;
- infrastructure and lifeline requirements;
- disclosure requirements and posting of signs;
- disaster response planning;
- reconstruction and redeveloping planning;
- public information and education programs; and
- strategies for maximizing political support.

Policy statements on all of these strategies can become a part of the safety element of a jurisdiction's general plan. However, these GENERAL PLAN POLICIES MUST BE BACKED BY PROGRAMS, ORDINANCES AND REGULATIONS TO HAVE ANY MEANINGFUL IMPACT ON OUR SAFETY.

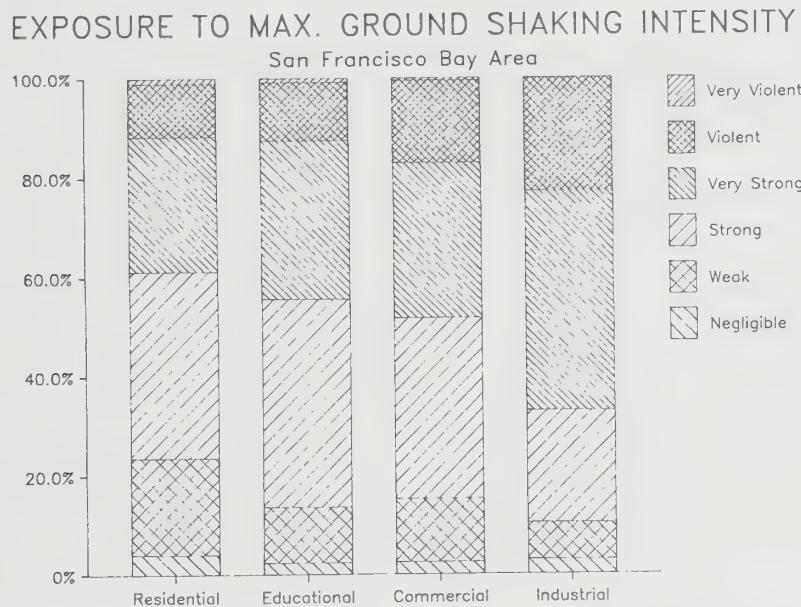
Such regulations rely on local government staff for enforcement. Many of the better ordinances are complex; adequate and continuing education and continuing training of local personnel are essential.

The local agency is in the forefront... because local government is at the action level and earthquakes do provide action.

James E. McCarty
Retired Oakland Public Works Director

1. Land Use Controls

Historically, strong economic and transportation pressures have caused industrial development to occur near the Bay. This area has soils that tend to be exposed to the strongest shaking. Without conscientious efforts to reverse this trend, future industrial development will continue to be exposed to more violent shaking than residential areas. Bay Area jurisdictions still have opportunities to avoid mismatches between land and use.



One reason that such efforts have not been made is due to a misunderstanding on the part of many outside of the earthquake field; many believe that avoiding building on actual fault traces is sufficient mitigation for all earthquake-related hazards, including shaking. A State law, the Alquist-Priolo Special Studies Zones Act, requires geologic studies and prohibits development on faults designated by the State Geologist. This program is only a small beginning.

The Alquist-Priolo Act deals with less than one percent of the earthquake problem.

James Slosson
Former State Geologist

Since earthquake hazards are only one factor in land use decisions, it may be impractical to ban all development on, for example, Bay mud. However, critical facilities such as emergency response centers, fire and police stations, and hospitals could be prohibited in Bay mud areas by most jurisdictions. More important, when weighing the implications of siting major facilities in alternate locations, the exposure to shaking should be a part of the siting decision, along with other economic, environmental and social concerns. Earthquake hazard maps are helpful in such a site screening process by identifying areas that should be easier to develop in a safer manner. In addition, these maps can alert decisionmakers early in the siting process that the costs associated with both potential damage and necessary hazard mitigation may be significant. Such screening has occurred with nuclear power plants and LNG facilities. Local zoning could also prohibit industrial development that uses significant amounts of hazardous materials in areas with high earthquake vulnerability.

2. Geotechnical Studies and Environmental Assessments

The National Environmental Policy Act (NEPA) requires an Environmental Impact Statement (EIS) be prepared for Federal action that may have significant environmental effects. The California Environmental Quality Act (CEQA) requires an Environmental Impact Report (EIR) be prepared for any public -- or private -- project that may have such environmental effects, including long-term health or safety risks. Soils, geology and earthquake-related hazards are routinely considered in these assessments. The process also requires appropriate mitigation. Even for developments that do not require EIRs, it is often useful to require appropriate soils and geologic investigations. EIRs can be required for subdivisions of land and planning documents (such as a city's General Plan), as well as actual building construction.

The quality of these studies and reports varies widely, due to the differing experience of the preparers and the local jurisdiction's review capabilities, as well as the amount of money available for underground testing. All jurisdictions can maximize the usefulness of these documents by:

- requiring the soils and geologic professionals to discuss the site in the context of the proposed development, rather than merely in its natural state;
- providing review of these documents by in-house geologists or soils engineers, or by such an expert that is retained on a contract;
- requiring the documents to formulate conclusions and suggest appropriate mitigation.

A POOR EXAMPLE--

THE SITE HAS 8 TO 15 FEET OF SANDY FILL, UNDERLAIN BY 70 TO 80 FEET OF SOFT GREY SILTY CLAY REFERRED TO AS "BAY MUD" ...THE BAY MUD IS COMPRESSIBLE AND WILL CONTINUE TO SLOWLY CONSOLIDATE FOR QUITE SOME TIME. BAY MUD IS ALSO SUBJECT TO SEVERE GROUND SHAKING IN THE EVENT OF EARTHQUAKES. ... THE PROBLEMS IDENTIFIED... ARE TYPICAL OF THOSE FOUND IN MUCH OF THE CITY [emphasis added]

A Recent Draft EIR for
a Bay Area City

Comment: Such statements can only perpetuate the myth that all ground is created equal. Although the description of the geologic conditions are accurate, such conditions are actually NOT typical of those in this city.

General statements that the Bay Area is exposed to earthquakes and that the site is ____ miles from the ____ fault are overly simplistic and do not reflect current knowledge on the effects of ground shaking.

3. Building Codes

The building departments of Bay Area cities and counties use the Uniform Building Code (which is revised every three years) as a minimum standard for earthquake-resistant structural design. Problems can develop, however, when the UBC becomes a "cookbook" and replaces design judgement. The Code has been developed to ensure a minimum standard of life safety, NOT to create "earthquake-proof" structures. Structural damage, damage to contents, and disruption of function in major earthquakes are expected in buildings designed "to Code".

Other problems in buildings can develop because of the lag between when Code language is written, adopted as part of the Code, and finally adopted by the local jurisdiction. For example, the most current code in 1987 is the 1985 UBC, yet many cities are still using the 1982 -- or even the 1979 -- version. At the same time, significant changes are being written to become a part of the 1988 UBC.

The Code is designed for standard rectangular buildings. Thus, little recognition has been given to problems that can arise when more complex configurations (both in plan view and elevation) are used. Such configurations are a trademark of contemporary architecture. However, the option does exist for the building official to require more sophisticated analysis. Additional requirements are being discussed for inclusion in the 1988 Code.

The Code contains a "soil factor" to deal with variations in ground shaking experienced on rock and firm soil, as opposed to moderately soft, and finally soft, soil. The seismic-resistant design requirements on soft soil are currently 1 1/2 times those for rock. Because of the types of problems expected on thick Bay mud, the addition of a fourth category of soil for such mud more than 40 feet thick is being discussed for inclusion in the 1988 Code. The requirements will be 2 times those on firm soil and rock.

Finally, small structures, including many single-family homes, are not required to have professional design. Thus, these small structures are more likely to incorporate "cookbook" design and use less than state-of-the-art design judgement.

Cities and counties can combat some of these deficiencies, and therefore improve the quality of new construction, by:

- promptly adopting new Codes as soon as legally permissible;
- requiring a structural engineer to provide design sign-off on all buildings (except, perhaps, one and two family wood-frame dwellings) to be located in areas subject to higher than average ground shaking risk or with complex configurations;
- considering adoption of a higher soil factor for buildings on Bay mud as quickly as feasible; and
- improving the qualifications and encouraging specialized training of local building department personnel responsible for structural review.

REDWOOD CITY'S INNOVATIVE CODE REQUIREMENTS

Redwood City has incorporated stringent and innovative requirements for areas of Bay mud into the City's Code that were prompted by development of Redwood Shores. These requirements include "special foundation design criteria, design provisions for greater lateral force, foundation systems to resist settlement, wood-frame sheathing, moment-resisting frames, response spectrum, reinforced masonry construction, elements of structural redundancy, and reinforcement of structural members" (Brown and Kockelman, 1983).

4. Non-Structural Mitigation

Even if the structural portions of a building are undamaged or only slightly damaged, many of the *non-structural* elements of the building may be damaged so that the businesses in the building may no longer be able to function. *Non-structural* elements include electrical and mechanical equipment, pipes and ducts. They also include elevators, file cabinets and computer equipment.

Following the San Fernando earthquake, the State passed legislation to require that new hospitals remain functioning following an earthquake. The nuclear power industry has also been acutely aware of the need to prevent damage to non-structural components which would hamper safe shut down following an earthquake. The techniques developed for these two types of facilities, as well as by industries in Japan, can serve as a model for non-structural mitigation by businesses in California. Techniques include various types of seismic restraints, including:

- bracing of critical pipelines and tank supports;
- anchoring machines, furniture, suspended ceilings and tanks to the floor and one another; and
- strapping of cylinders, cabinets, containers and shelving.

Other techniques include special pipe connections, automatic shutoff valves, special computer center floors, specifically engineered materials and joints, contingencies for loss of power, and maintenance.

Residences can also make use of some of these techniques, as described in the section on public education (page 29).

These techniques may prove especially valuable in areas that are more likely to experience severe ground shaking.

REDWOOD CITY -- CONTINUED

Redwood City has non-structural requirements that are part of the special ordinance discussed earlier that apply to the entire city, "Whenever connected to, parts of, or housed within a building or structure, towers, tanks, storage-type water heaters, lighting fixtures, power transformers, machinery or other equipment that could constitute or contribute to earthquake hazards shall be securely anchored ... Domestic storage-type water heaters installed in one and two story residential buildings shall be anchored..." (Ord. No. 1727, Section 2, 11-28-77).

5. Existing Hazardous Buildings

Collapse of buildings or collapse of portions of buildings are the most recognized threats to life safety during an earthquake.

California At Risk
Seismic Safety Commission, 1986

The San Francisco Bay Area contains thousands of buildings that will be more likely to be extensively damaged in future earthquakes than those being built today.

Unreinforced masonry buildings are statistically the type of structure most susceptible to damage. Recently, the State (through SB 547) mandated each local government in California to identify all unreinforced masonry buildings in its jurisdiction and establish a local program. There are approximately 5,000 unreinforced masonry buildings in the nine-county Bay Area. Over 2,100 of these buildings are located in the City of San Francisco. The City has completed the first phase of this state-mandated process by identifying the addresses of these buildings. In addition, in order to design a program for mitigating the hazard, the City's Bureau of Building Inspection is gathering additional information on these structures. ABAG staff has been working with Bureau staff to provide the level of earthquake hazard for each building location. This information on the relative risk of the ground will be added to information on building occupancy and used in designing the mitigation program. It is unknown at this time whether or not differences will be significant enough to warrant differences in mitigation priorities or timing for different neighborhoods based on the geologic materials, maximum ground shaking intensity, or risk of damage. Seven cities have developed programs for identification, analysis or repair of unreinforced masonry buildings, including Long Beach, Los Angeles, Santa Ana, Santa Rosa, Sebastopol, Morgan Hill and Palo Alto. However, none of the mitigation programs currently existing have used this type of information. San Francisco may. Such a program may be overly complex for many cities with only a couple of dozen such buildings.

Although unreinforced masonry buildings have become a symbol for hazardous buildings, they are by no means the only potential problem. Many older cities are dominated by wood-frame homes over 50 years old which were built before such buildings were required to be bolted to their foundations. Cities may want to require bolting when such buildings are sold. Because of the large number of such buildings, cities may find it appropriate to first target neighborhoods "on shakier ground".



6. Hazardous Materials

Hazardous materials are defined in various state and federal regulations. In general, however, a hazardous material is a substance or combination of substances which, because of quantity, concentration, physical, chemical or infectious characteristics may either:

- (1) cause, or significantly contribute to, an increase in deaths or serious illnesses;
or
- (2) pose a substantial present or potential hazard to humans or the environment.

Earthquakes have caused a number of hazardous material problems in the past related to pipeline breaks, tank failures, falling containers and shelves, sliding and overturning industrial equipment, and transportation accidents.

Local government mitigation programs should start with a comprehensive risk assessment, including:

- an inventory of hazardous materials (required by AB 2185); and
- an assessment of the location of these materials relative to the types of hazard maps included in this booklet.

(Others may want to include a structural and non-structural analysis of particular facilities.)

Based on the perceived risk, local governments may want to:

- modify local zoning to restrict development on areas of high risk of damage;
- prohibit storage or handling of hazardous materials in buildings that are seismically suspicious (such as unreinforced masonry buildings) until such structures are retrofitted to an acceptable level of safety; and
- conduct periodic inspections of non-structural aspects of buildings in which hazardous materials are located as part of fire department inspections.

Several options for non-structural hazard mitigation are available, including:

- inventory control;
- seismic restraints;
- special pipe connections;
- safety shutoffs;
- special gas storage tanks;
- raised computer floors;
- secondary containment;
- specialized engineered materials;
- contingencies for loss of power; and
- maintenance.

Education and training of both local government inspectors and company employees are essential.

7. Infrastructure or Lifelines

Public utilities and transportation systems comprise perhaps one-half the property at risk in earthquakes.

J. Isenberg
Social and Economic Impact
of Earthquakes on Utility Lifelines
American Society of Civil Engineers, 1980

Roads and pipelines and wires cannot avoid areas of intense ground shaking or the Bay Area would have to function as a series of islands -- an obvious impossibility. A second problem exists: lifeline earthquake engineering and regulations have lagged behind structural engineering.

Yet many of the principles stressed in earlier sections have applications to lifelines:

- site selection for central facilities;
- building or structure construction;
- equipment bracing, protection, and strengthening; and
- pipeline design.

In addition, since lifelines are systems, additional principles can be applied, including:

- redundancy;
- flexibility; and
- rapid repair.

Local governments may be tempted to approve developments in areas of Bay mud or subject to severe shaking when told that the buildings being proposed can be designed to suffer minimal damage. However, that government, when approving these buildings, should be aware that it is also approving the local roads, sewers, water, energy, and communications that will be required. Installation, maintenance and repair of these lifelines are paid for by their tax-paying or rate-paying constituents. Anyone who has driven to the Berkeley Marina on the buckled road or who knows about the utility problems at Emeryville's Watergate begins to comprehend the level of damage that could occur on Bay mud if it is heavily shaken.

RETROFITTING HIGHWAY BRIDGES

One of the most visible effects of the San Fernando earthquake in 1971 was the collapse of highway bridges. A State program was developed to retrofit State and federal highway bridges. The order in which these structures were retrofitted was based on a priority system which included the expected acceleration at the site as a measure of ground shaking risk. The State retrofit program was essentially complete at the end of 1986. Almost \$15 million was spent to retrofit approximately 300 bridges in CALTRANS District 4 (which includes almost all of the nine Bay Area counties). Bridges and overpasses on local roads are not a part of this State program. San Francisco has started a similar program for its local bridges.

8. Disclosure Requirements

The federal government "requires lenders to notify prospective borrowers that the real estate being mortgaged is located in a flood-hazard area." As part of the Alquist-Priolo Special Studies Zones Act discussed earlier, California "requires a seller or his agent to inform the prospective buyer that the real estate is located within a fault rupture zone, as delineated by the State Geologist" (Brown and Kockelman, 1983). Santa Clara County has gone one step further. "In an ordinance enforcing onsite geologic investigations before construction, the ... County ... requires all sellers of real estate lying partly or wholly within the County's flood, landslide, and fault-rupture zones to provide the buyer with a written statement of the geologic risk" (Brown and Kockelman, 1983).

With this background, the question then becomes: Is it appropriate for a local city or county to require disclosure of the information on the type of maps contained in this report to potential buyers of real estate? Given the relative nature of the risk, it is likely that the information would be misunderstood. The information is also better viewed as an indication of the risk of a neighborhood rather than of any individual building. Thus, such a requirement may cause much confusion and little education. It is appropriate, however, to require the disclosure of the conclusions and recommendations contained in geotechnical investigations for individual projects.



photo courtesy of the U.S. Geological Survey

9. Disaster Response Planning

Effective emergency response means the capability has been established, and is being maintained, to provide such services as fire suppression, emergency medical care, emergency communications, evacuation and temporary shelter, search and heavy rescue, public information, and identification of buildings and other structures that earthquake damage has rendered hazardous. Effective emergency planning requires that the agencies and personnel who provide these services are trained, equipped, organized, and prepared to deal with a major disaster and that state emergency coordinators have detailed knowledge of how the response system operates.

Seismic Safety Commission
California At Risk, 1986

A critical ingredient in emergency response training is regular and realistic emergency response exercises. Earthquake scenarios are routinely used in the development of these exercises. ABAG has produced intensity maps of the region for ten different earthquake source faults or fault segments that are available at a scale of 1:250,000 (one inch = approximately four miles). In addition, general building stock data are available for the approximately 1200 census tracts in the region. These data can provide managers with the ability to develop a series of earthquake exercises for several different hypothetical earthquakes. Although space in this booklet prohibited the inclusion of all ten scenario maps, the two intensity maps provided for the San Andreas and Hayward faults depict the greatest sources of risk for the central Bay Area.

The individual intensity maps confirm that many moderate earthquakes will affect only portions of the Bay Area. Mutual aid agreements should prove valuable in improving the effectiveness of local emergency response capabilities by providing help when emergency needs are greater than a single jurisdiction can handle. Because of the subregional nature of these moderate events, it is critical that the network of mutual aid agreements should be regional and not limited to jurisdictions within a single county. Local government emergency staff should review current mutual aid agreements to ensure that they include cities that will be severely affected, as well as only slightly affected, by the various hypothetical earthquakes. These agreements are currently limited to police and fire protection. The State Seismic Safety Commission (1986) has recommended that "this concept needs to be extended beyond police and fire protection to additional key services including emergency medical care, transportation, and public works."

Local emergency services staff should evaluate the location of emergency operations centers, communications systems, and fire and police stations relative to the various ground shaking intensity maps. The maps should provide a tool in screening locations for future emergency facilities, as well.

10. Reconstruction/Redevelopment

Existing hazardous buildings can be structurally upgraded, or rehabilitated. Two other options exist for dealing with existing development that is unsound or in hazardous areas -- reconstruction and redevelopment.

Reconstruction following an earthquake can give local governments the opportunity to rebuild to newer building codes and to relocate some activities on less shaky ground.

Some of our elected officials believe in "Structural Darwinism," that is, that there is no need to do anything about bad buildings because the earthquake will get rid of the unfit buildings.

Anonymous local government
staff member

However, relying on reconstruction at the expense of other mitigation alternatives is irresponsible. Based on research related to past earthquakes, there are tremendous political, economic and social incentives for rebuilding in the same location. In addition, local building inspectors and planners will be swamped by building permits and plans; they will not have adequate time to thoroughly review applications. Finally, buildings damaged in earthquakes kill and injure people. And the people who live and work in those buildings can become temporarily homeless and unemployed. The social and economic implications of ignoring such buildings are severe. Such problems can be lessened somewhat if local governments make plans NOW for reconstruction and limit use of reconstruction to areas where other strategies are not feasible.

Redevelopment can be used in older downtown areas as part of local programs for improving deteriorating areas. Cities have the authority to issue redevelopment bonds for use in demolition and rehabilitation of unsafe buildings. Bond payments are made from the incremental new revenues generated from the new developments in the area. Because many unreinforced masonry buildings are located in older commercial areas, this technique is particularly useful in financing demolition or rehabilitation of these unsafe structures. (Other financing mechanisms for private structures exist, including a recently revised federal tax credit of 10% for buildings built before 1936 or 20% for certified historic structures designated by the National Park Service or listed on the National Register.)



11. Public Education

Local government cannot respond to earthquakes on its own. It must rely on others to help mitigate hazards before an earthquake, as well as respond to the disaster in a responsible manner. The need is, then, to contact and educate the various community sectors who will be sharing the earthquake mitigation work. There are three principal locations for reaching people:

- at school;
- at home; and
- at work.

All education strategies begin with establishing an EARTHQUAKE THREAT. The maps contained on the previous pages can be used to establish that:

- the Bay Area is earthquake country;
- the epicenter is NOT ground zero; and
- all ground will not shake in the same manner.

Next, people need to understand what to expect in terms of DAMAGE. Photographs can help illustrate:

- What does intensity mean?
- How do building structures react?
- What can happen to building contents?

Finally, it is essential that people do not perceive an earthquake as an overwhelming disaster that cannot be prevented. MITIGATION strategies can be illustrated:

- for choosing a home or office location;
- for performing a rudimentary structural walk-through;
- for hunting for non-structural problems (and how to fix them); and
- for responding to the earthquake itself.

Strategies for responding to non-structural hazards at home might include, for example:

- anchoring the tops of heavy bookcases and china cabinets into the wood studs with angle brackets (bolts in sheetrock pull out);
- strapping and anchoring home water heaters;
- using Velcro strips to help prevent heavy objects from falling from shelves;
- ensuring that cabinets (especially those containing cleaning supplies and liquor) are secured to walls and have doors with secure latches;
- avoiding the use of heavy mirrors or pictures (especially pictures with glass) above beds.

Government and the private sector must function as a team.

To actually get people to ACT on information is the trick. Repeated contacts can kick people into action.

Battalion Chief O'Donnell
Daly City Fire Department

12. Political Support Strategies

Local planning commissioners and elected officials are those ultimately responsible for implementing aggressive ground shaking mitigation programs. Developing and implementing such programs require a commitment of staff time and dollars in an era of severe budget constraints. Finding the time and resources for earthquakes often means less for sewers, streets and libraries. Gaining support means doing some homework on the threat to a particular city -- as well as options for mitigating that threat. The following three ideas may help in designing such a program. Another source of information is the report on the State's five-year plan for reducing earthquake hazards, California at Risk (Seismic Safety Commission, 1986).

1. ESTABLISH THAT IT WILL HAPPEN IN YOUR CITY

Thousands of people killed in a few seconds is going to blow the lid off this country, and it's going to happen.

Karl Steinbrugge -- Former Chair
California Seismic Safety Commission

General statements such as this one by Karl Steinbrugge wake people up. But a sophisticated system of denial then begins to operate -- "It's not a problem in my city, but in one of the other cities in the Bay Area." Earthquakes will cause damage in every city in the region. Experts estimate that one of every 100 people in the Bay Area may be killed or so seriously injured that they will need to be hospitalized in the next great earthquake. All of those casualties will not occur in San Francisco. ABAG's intensity maps can be one piece of information needed to develop a local risk assessment.

2. PROVIDE DATA TO SHOW THAT NEW PROGRAMS ARE ECONOMICALLY WISE

For every dollar of physical damage one can expect at least 2-1/2 dollars of economic impact.

Bay Area Earthquake Preparedness Project
Networks, Winter 1987

Local governments revenues are derived from property taxes and sales taxes that will be impacted by earthquakes. And earthquakes will place those same governments in a position of needing additional revenues to build and repair their own facilities.

3. TAKE ADVANTAGE OF OPPORTUNITIES

Earthquake safety is NOT a technical issue -- but a political one.

Frank Lew -- Superintendent
San Francisco Bureau of Building Inspection

Establishing additional specialized programs is expensive. Earthquake concerns can be more effectively built into existing programs. Examples of such programs include:

- revising procedures for reviewing proposed new development;
- reviewing the safety element when the General Plan is updated to take advantage of new information;
- building earthquake education into fire inspection programs; and
- providing hazardous building data when designing redevelopment programs for older downtown areas.

ABOUT THE MAPS

The maps in this report are general and attempt to provide an overview of the relative hazard of various neighborhoods in the central San Francisco Bay Area. They can be used as a basis for requiring more site-specific geotechnical investigations. Those investigations may determine that a site should be in a different hazard category than indicated. Many of the maps are based on a particular model for predicting intensity. Although there is a disagreement in the scientific community on the most realistic model for producing such maps, none of the disagreements should be considered sufficiently large to prevent the use of these maps by local jurisdictions as one factor in designing programs to mitigate ground shaking damage.

The maps in this report are either 1:1,000,000 (1"=16 miles -- the fault map) or 1:125,000 (1"=2 miles -- the remaining seven maps). ALL eight of these maps are available as single-color blueline prints at a scale of 1:250,000 (or 1"=4 miles) for the entire nine-county San Francisco Bay Area for a nominal charge to cover reproduction. The three risk maps have been produced at 1:62,500 (1"=1 mile) in color for San Mateo County only. The U.S. Geological Survey is publishing these maps in 1987. Special computer print-out maps of smaller areas can be produced on request at any scale, including 1:62,500 (1"=1 mile) for a charge to cover computer and staff time (usually a few hundred dollars).

A total of 20 earthquake hazard maps are available as blueline prints at the scale of 1:250,000. These maps include the ENTIRE NINE BAY AREA COUNTIES.

- Fault Traces (used as sources of ground shaking)
- Alquist-Priolo Special Studies Zones (for fault surface rupture)
- Geologic Units (grouped into categories of similar susceptibility to ground shaking)
- Ground Shaking Intensity from an Earthquake on the San Andreas Fault
- Ground Shaking Intensity from an Earthquake on the Northern San Andreas Fault
- Ground Shaking Intensity from an Earthquake on the Southern San Andreas Fault
- Ground Shaking Intensity from an Earthquake on the Hayward Fault
- Ground Shaking Intensity from an Earthquake on the Calaveras Fault
- Ground Shaking Intensity from an Earthquake on the Northern Calaveras Fault
- Ground Shaking Intensity from an Earthquake on the San Gregorio Fault
- Ground Shaking Intensity from an Earthquake on the Concord-Green Valley Fault
- Ground Shaking Intensity from an Earthquake on the Healdsburg-Rodgers Creek Fault
- Ground Shaking Intensity from an Earthquake on the Maacama Fault
- Maximum Ground Shaking Intensity
- Cumulative Damage Potential from Earthquake Ground Shaking for Tilt-Up Concrete Buildings
- Cumulative Damage Potential from Earthquake Ground Shaking for Concrete and Steel Buildings
- Cumulative Damage Potential from Earthquake Ground Shaking for Wood Frame Dwellings
- Liquefaction Susceptibility
- Liquefaction Potential
- Dam Failure Inundation Areas

REFERENCES

This booklet is intended to provide non-technical documentation for eight of ABAG's earthquake hazard maps. In addition to the maps available at 1:250,000 for the entire region, there are two documents intended for those wanting more complete technical documentation.

A Guide to ABAG's Earthquake Hazard Mapping Capability.

Revised 1983, 60 pages -- Describes ABAG's development of hazard maps using a computer-based geographic information system. Includes page-sized versions of many available maps. Describes 20 maps available at 1:250,000 and Working Papers available at additional cost.

Earthquake Mapping Project Working Paper #17 -- Using Earthquake Intensity and Related Damage to Estimate Maximum Earthquake Intensity and Cumulative Damage Potential from Earthquake Ground Shaking. (text only) -- Revised December 1983.

For those wishing to prepare mitigation programs, the following reports are recommended:

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ASSOCIATION
OF BAY AREA
GOVERNMENTS

MetroCenter
Eighth & Oak Streets
Oakland
(415) 464-7900

Mailing Address:
P.O. Box 2050
Oakland, CA 94604-2050

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